MEASURING COUPLINGS IN TWO HIGGS DOUBLET MODELS

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William and Mary

1. Precision measurements of the 125 GeV Higgs.
2. Charged Higgs
3. Could the 125 GeV Higgs be the heavier of the two?

Recent references (2012-3)

Branco, Ferreira, Lavoura, Rebelo, MS, Silva, 1106.0034, Physics Reports 516 (2012) 1-102

Papers that look at Higgs(125) couplings in the 2HDM and compare with data.

P. Ferreria, R. Santos, MS, J. Silva, 1112.3277 (based on early data, pretty crude)

D.S. Alves, P.J. Fox, N.J. Weiner, 1207.5499 (type I, looked at enhancing diphoton signal, added fields to correspond to susy)

N. Craig, S. Thomas, 1207.4835 (all 4 2HDMs, comprehensive analysis using data presented in July).

N. Craig, J. Evans, R. Gray, C. Kilic, M. Park, S. Somalwar, S. Thomas, 1210.0559 (all 4 2HDMs, focused on multi-lepton signals.)

Y. Bai, V. Barger, L. Everett, G. Shaughnessy, 1210.4922 (all 4 2HDMs, detailed fits to July data)

C-Y. Chen, S. Dawson, 1301.0309 (all 4 2HDMs, includes constraints from B physics, plots of coupling fits, updated to include CMS diphoton results).

Assumptions for this talk

1. No supersymmetry
2. No singlets (2HDM only)
3. No CP violation in Higgs Sector.
4. No custodial symmetry breaking
5. No tree-level FCNC

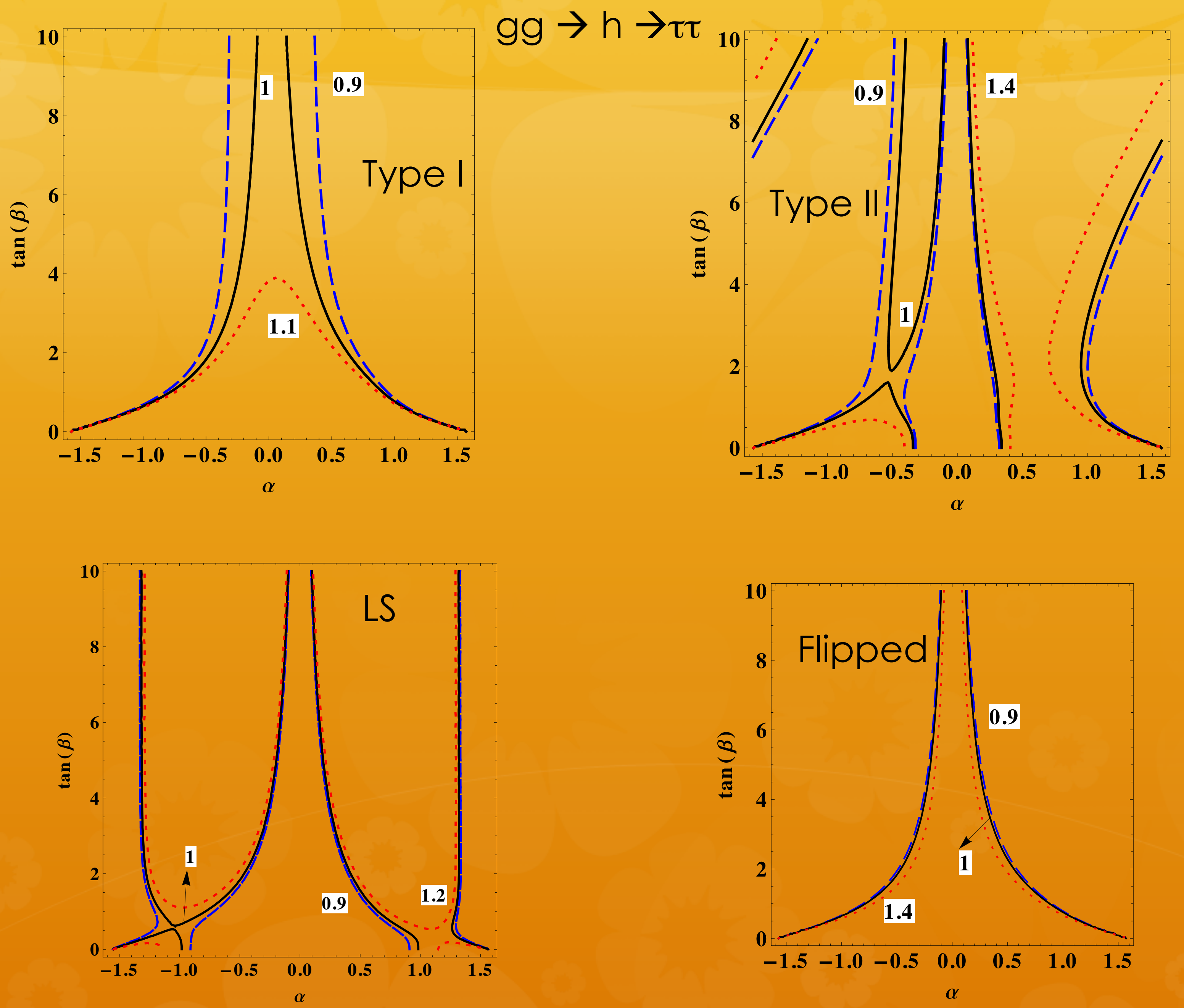
Relative couplings to the SM, with h being the light neutral Higgs and H being the heavy neutral Higgs. tan $\beta = v_2/v_1$ and α is the neutral scalar mixing angle.

	Type I	Type II	Lepton-specific	Flipped
ξ_h^u	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
ξ_h^d	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
ξ_h^ℓ	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$
ξ_H^u	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$
ξ_H^d	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$
ξ_H^ℓ	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos\alpha/\cos\beta$	$\sin\alpha/\sin\beta$
ξ_A^u	$\cot\beta$	$\cot\beta$	$\cot\beta$	$\cot\beta$
ξ_A^d	$-\cot\beta$	$\tan\beta$	$-\cot\beta$	$\tan\beta$
ξ_A^ℓ	$-\cot\beta$	$\tan\beta$	$\tan\beta$	$-\cot\beta$

hVV: $\sin(\alpha-\beta)$ HVV: $\cos(\alpha-\beta)$

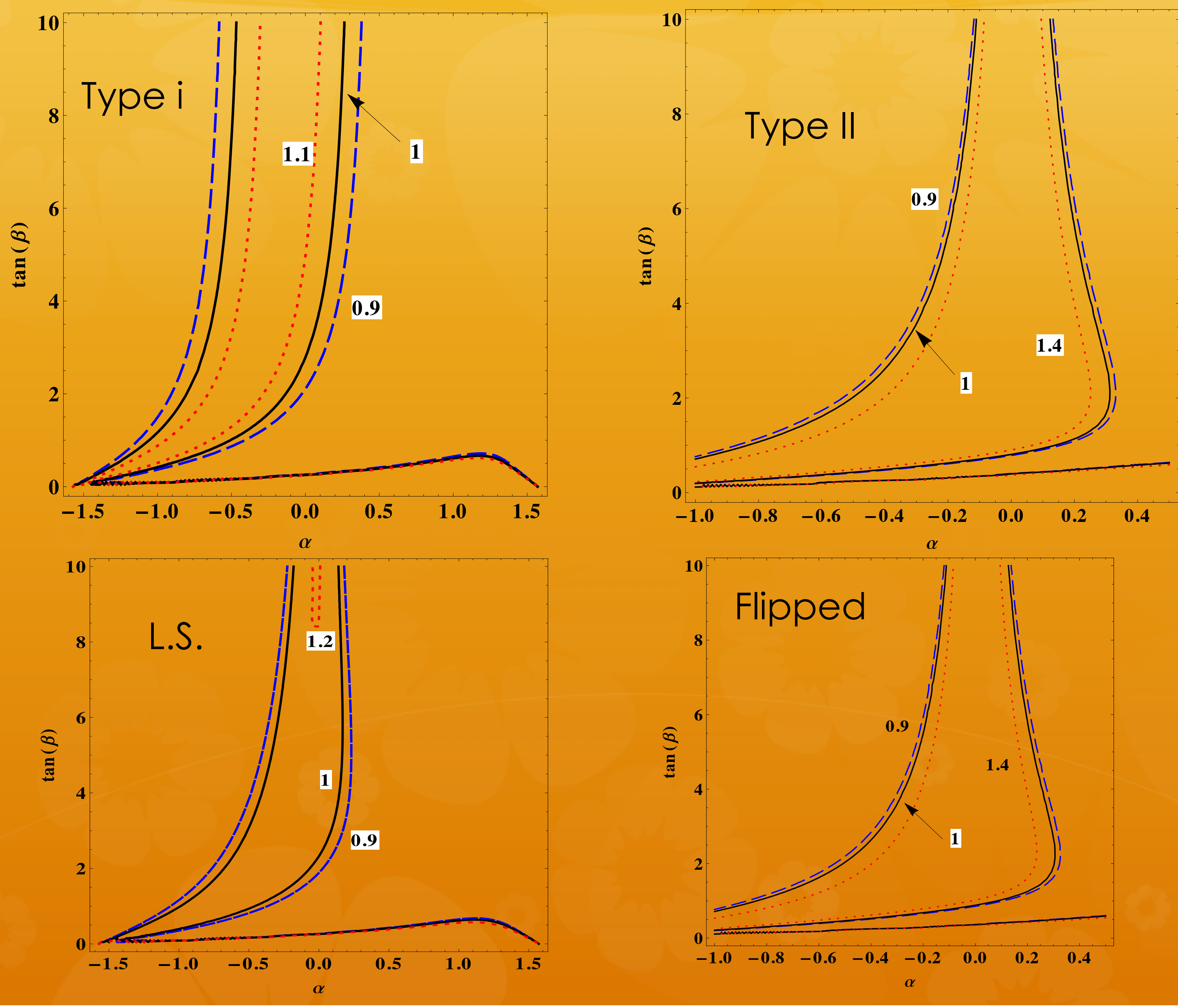
Note: if $\sin\alpha = -\cos\beta$ and $\cos\alpha = \sin\beta$, the couplings of h are the same as in the Standard Model.

gg → h →ττ

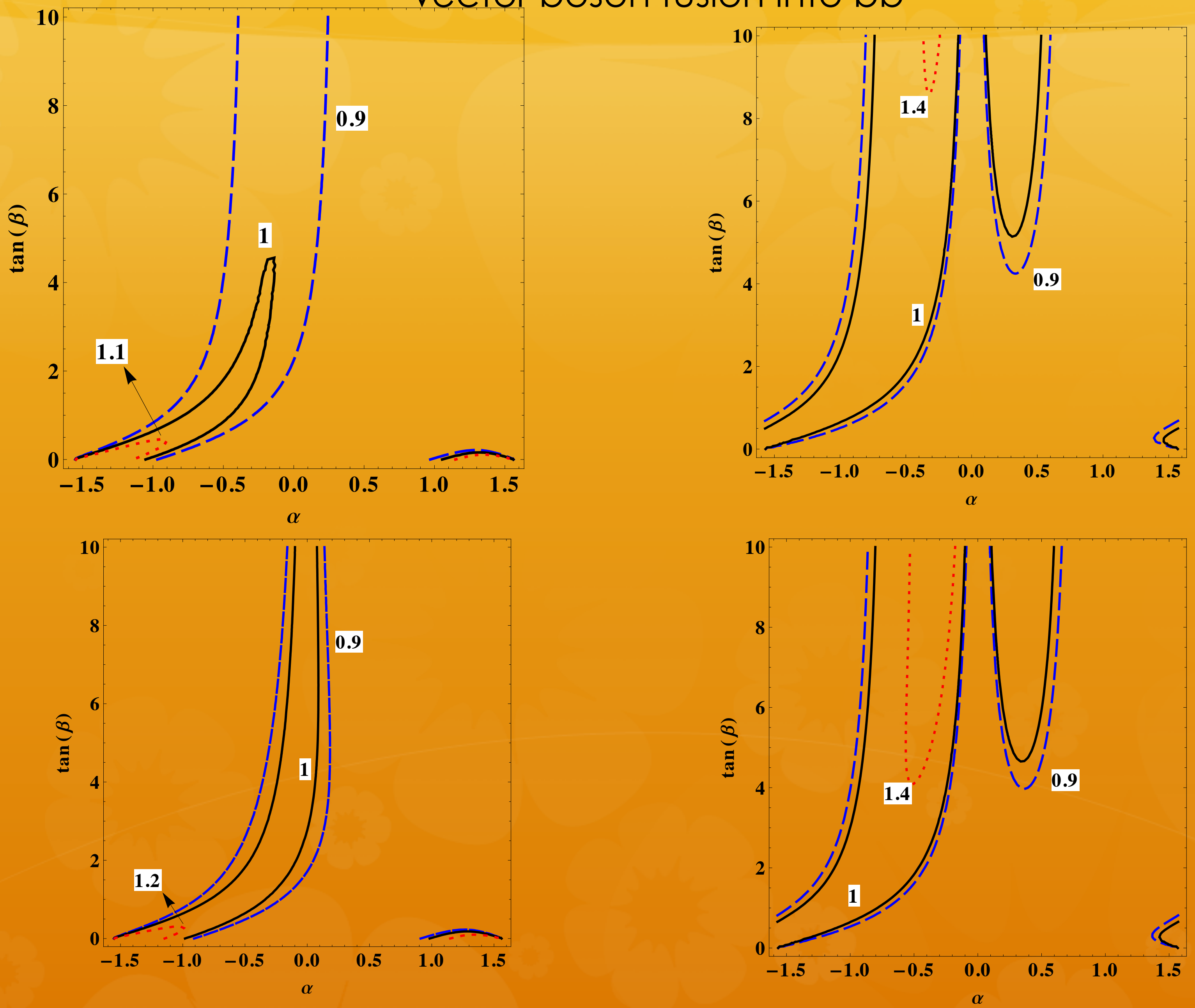


Chen, Dawson

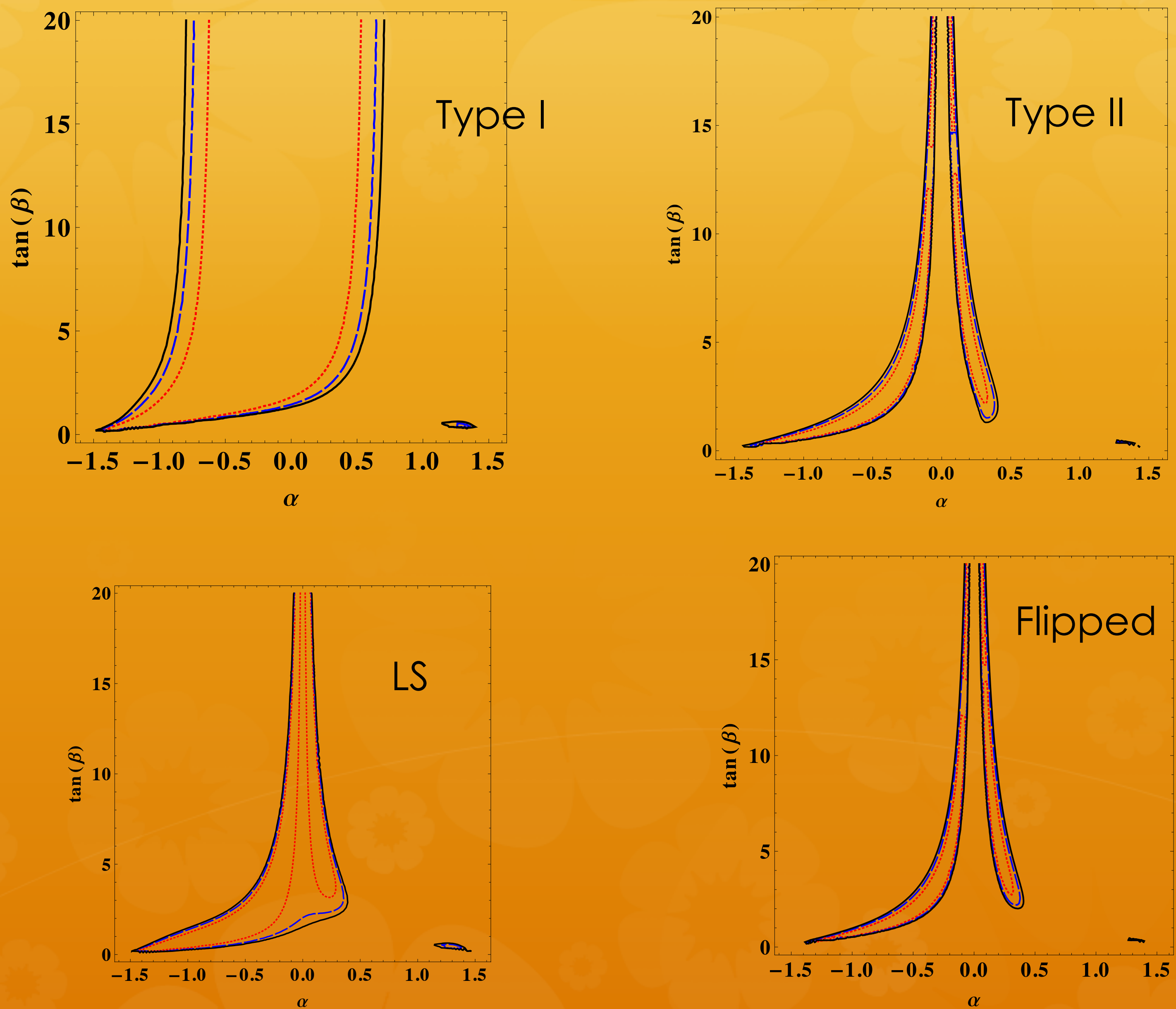
$gg \rightarrow h \rightarrow \gamma\gamma$



Vector boson fusion into bb

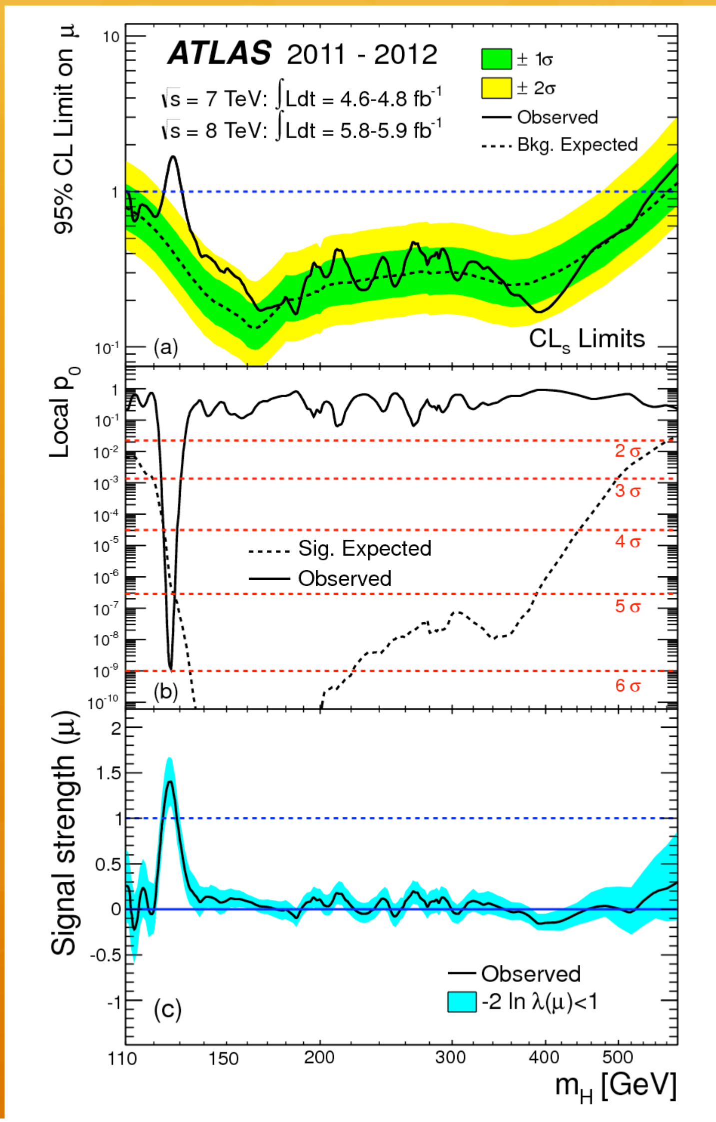


Allowed regions (including recent CMS diphoton results)

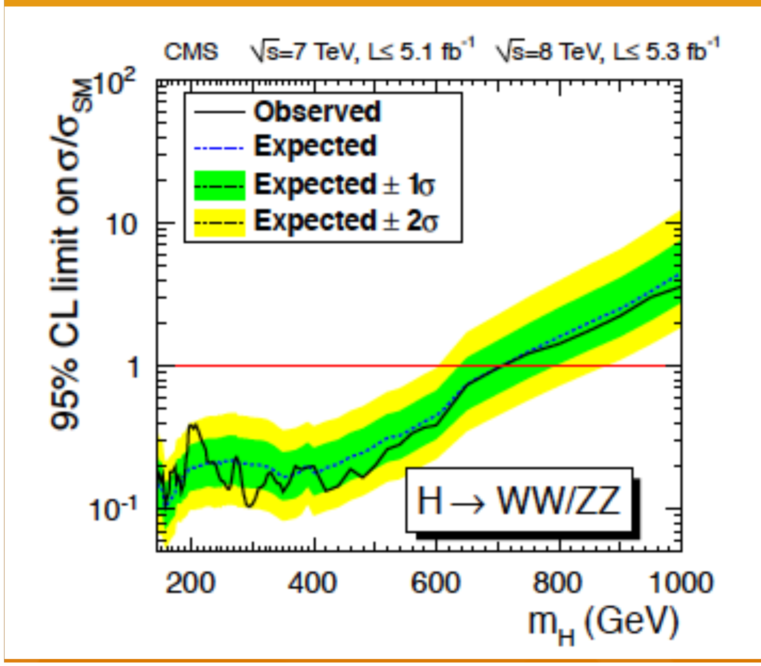


Black –99%
Blue – 95%
Red – 68%

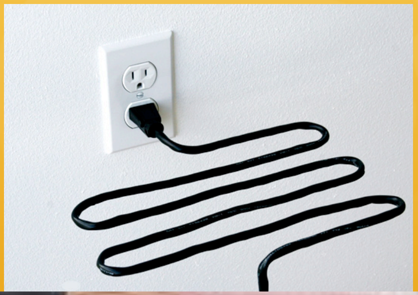
ATLAS/CMS bounded couplings of the heavy Higgs to ZZ, WW. This places an upper bound on $\sin^2\alpha/\sin^2\beta$. For modest $\tan\beta$, this gives an upper bound on $\sin^2\alpha$. For example, suppose the Brazil bands drop to 10^{-2} after a few years of running, then $\sin\alpha$ must be less than 0.1, which is a constraint that might be more restrictive than precision Higgs measurements.



This will, of course, be restricted to a large mass range for the H, and it assumes that H → hh is negligible (which is true except at large $\tan\beta$). Effects of current bounds are currently under investigation.



The Charged Higgs



$$\mathcal{L}_{H^\pm} = -H^+ \left(\frac{\sqrt{2}\, V_{ud}}{v}\, \bar{u}\, (m_u X P_L + m_d Y P_R)\, d + \frac{\sqrt{2}\, m_\ell}{v}\, Z \bar{\nu}_L \ell_R \right) + \text{h.c.}$$

Barger, Hewett, Phillips, PRD 1990

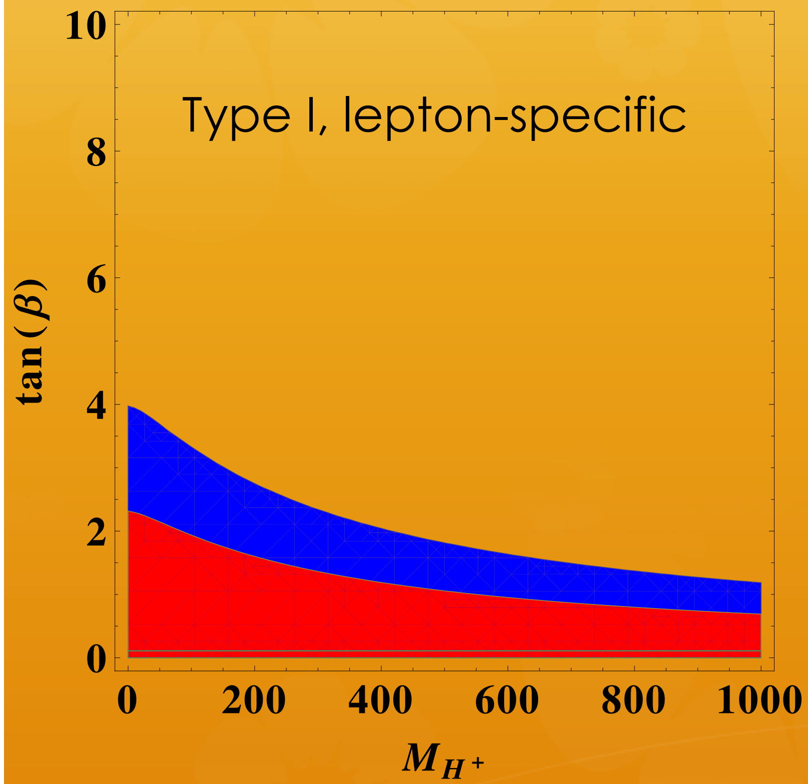
	Type I	Type II	Lepton-specific	Flipped
X	$\cot\beta$	$\cot\beta$	$\cot\beta$	$\cot\beta$
Y	$\cot\beta$	$-\tan\beta$	$\cot\beta$	$-\tan\beta$
Z	$\cot\beta$	$-\tan\beta$	$-\tan\beta$	$\cot\beta$

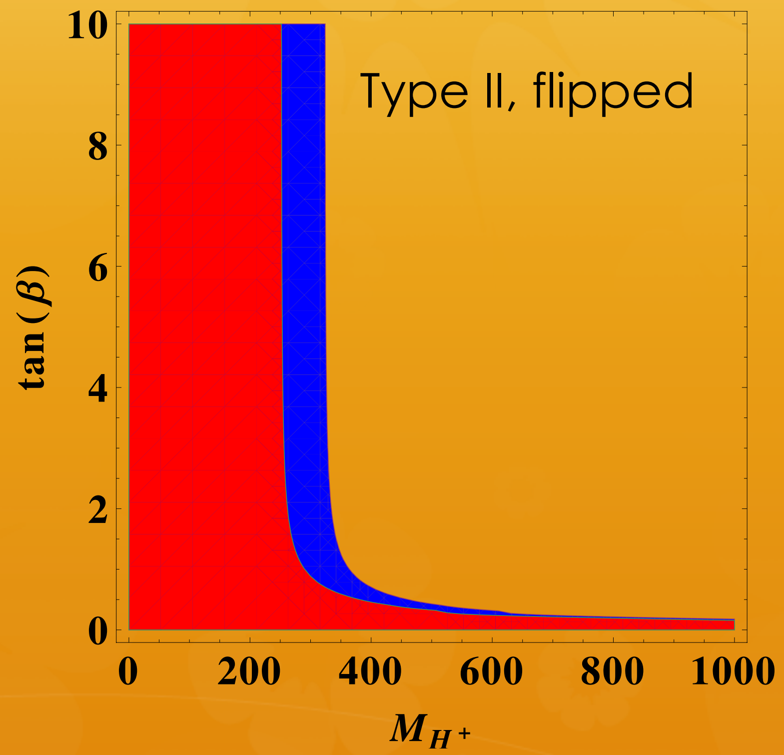
Type I -- for moderately large $\tan\beta$, the charged Higgs is fermiophobic

Type II -- coupling proportional to $m_t \cot\beta + m_b \tan\beta$ -- this has a minimum at $\tan\beta = 6$.

Strongest bounds on the charged Higgs mass come from $B \rightarrow X_s \gamma$

blue- 2σ, red - 3σ





Dozens of papers over the years, these are from Dawson, Chen 1301.0309

Other bounds from B-decays are either weaker or make more assumptions.
New physics beyond 2HDM can weaken these substantially.

First, we consider the case in which the charged Higgs is lighter than the top quark. This is the most studied case, since significant bounds can already be obtained.

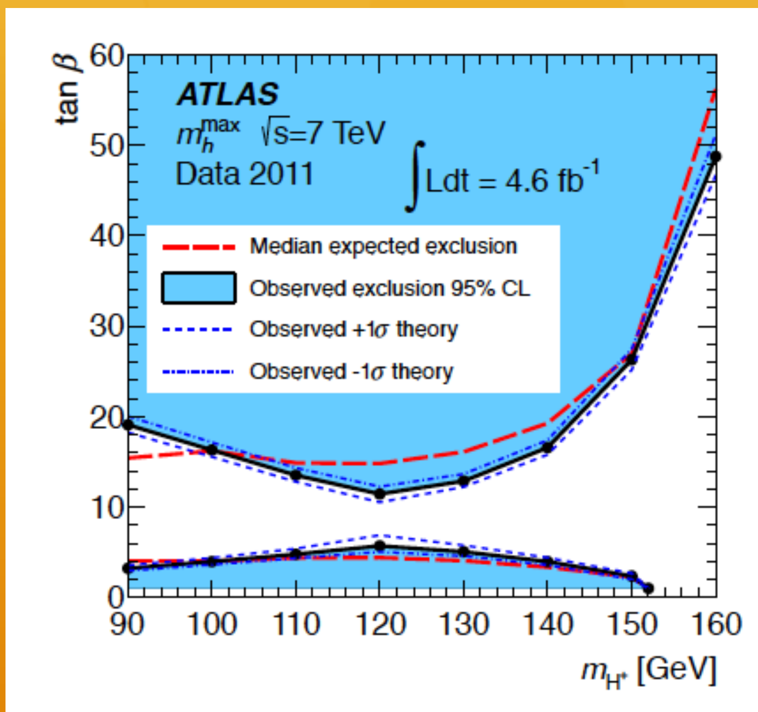
Experimenters determine the limit for the branching ratio for t -> H^+ b, and then convert into a bound in the M – tan β plane, saying things like:

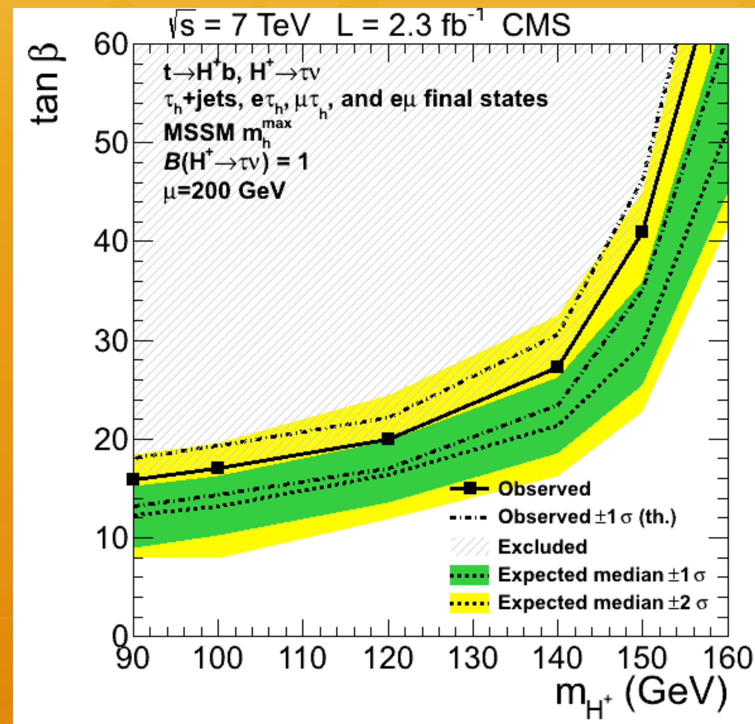
Interpreted in the context of the mmax h scenario of the MSSM, tan β above 12–26, as well as between 1 and 2–6, can be excluded in the mass range 90 GeV < mH+ < 150 GeV.

This is far too restrictive. Such specificity is needed for fine-tuning parameter-space, but the basic structure is more general

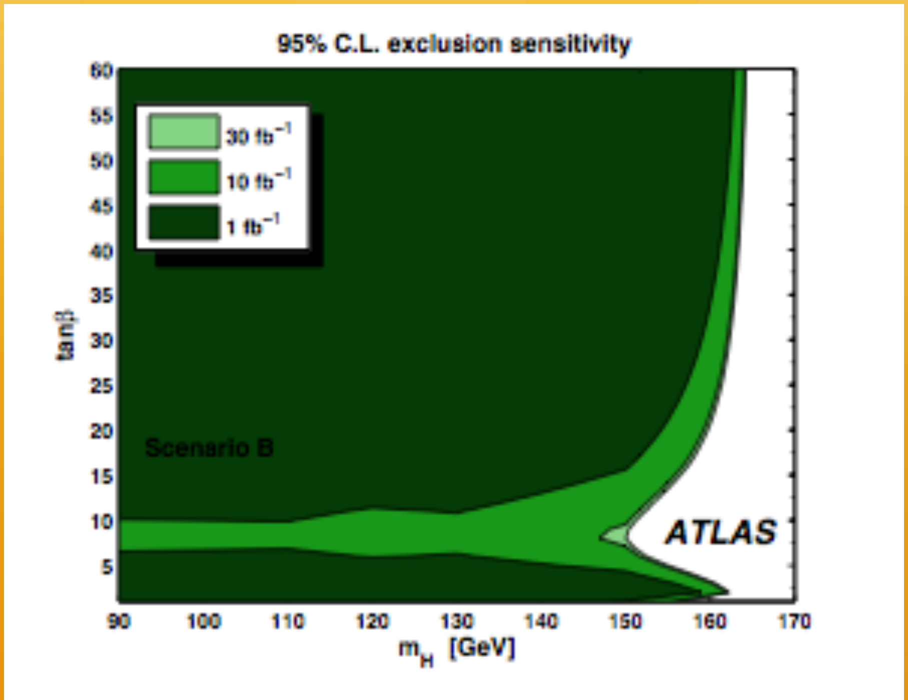
Latest results (from 2011 data)

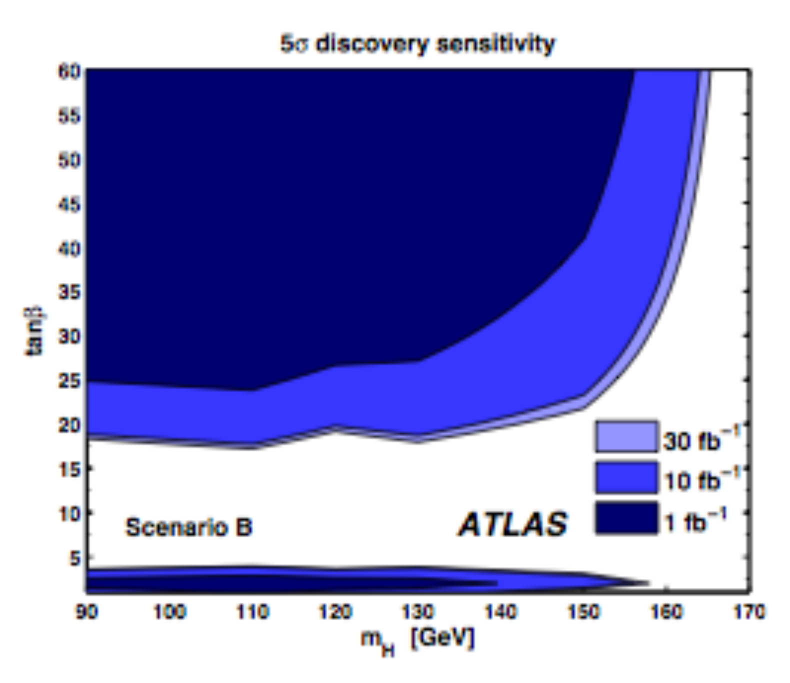
This is for the type II model.   For type-I, only the lower bound is relevant





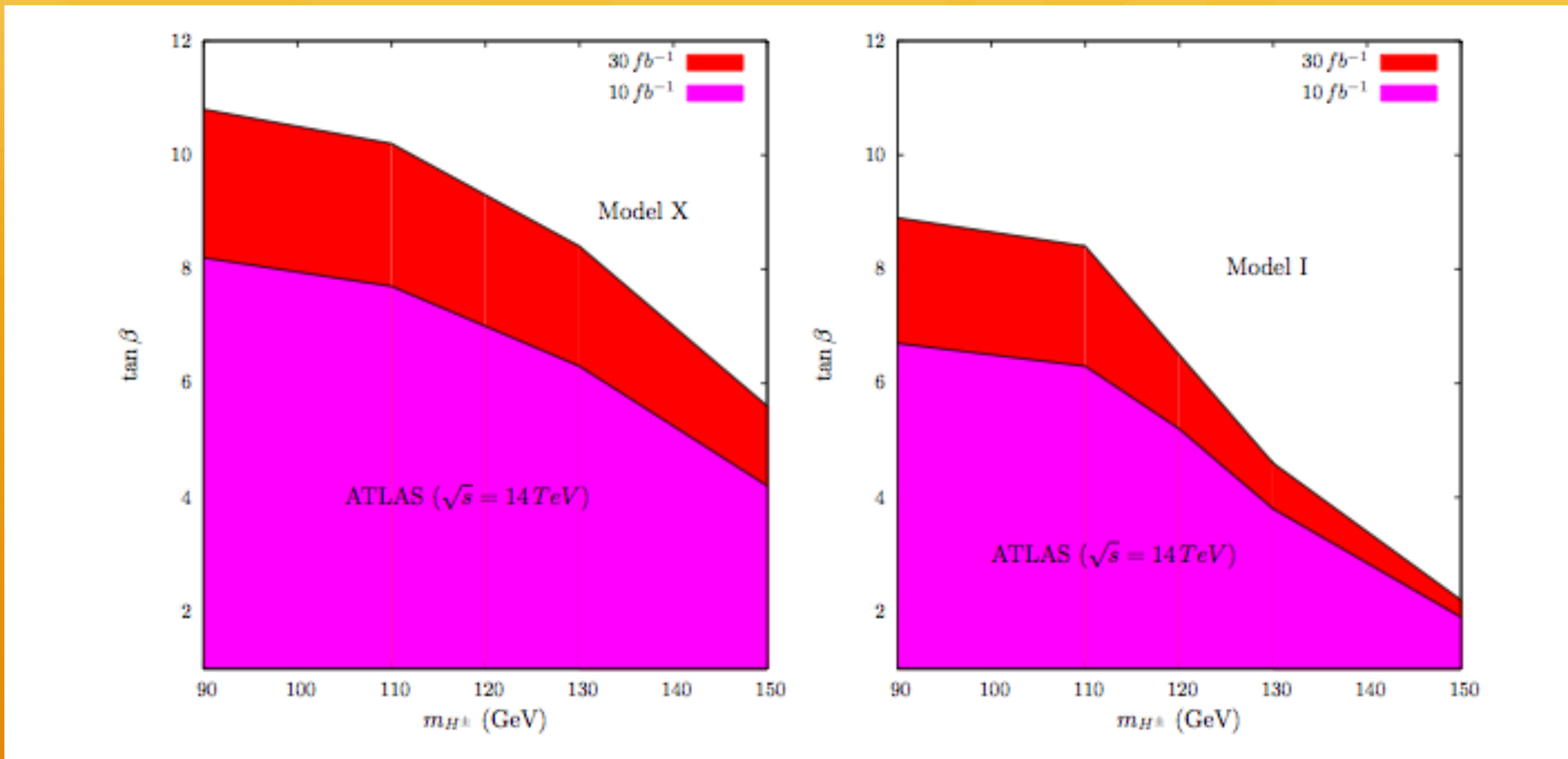
Including the 2012 data will improve the reach somewhat, possibly even excluding masses around 120-130 for all tan β, but the biggest improvement will happen shortly after 13 TeV is started.





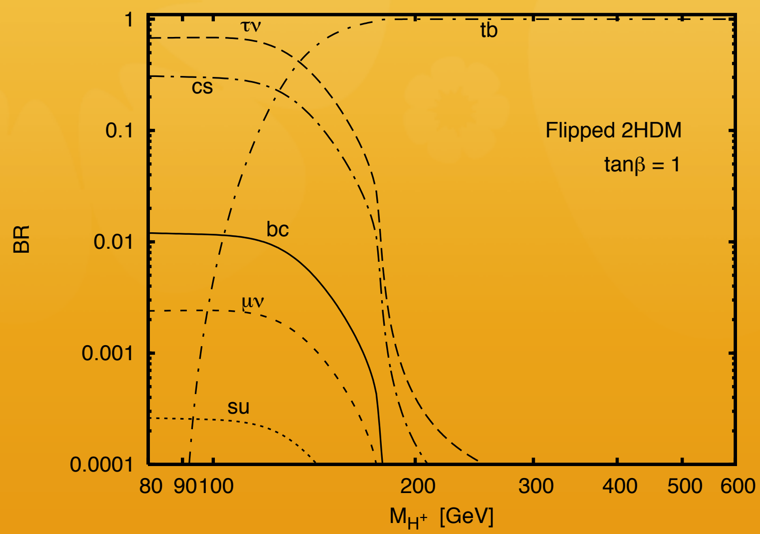
Thus, it will not be too long after start-up that the entire region up to 150 GeV could be excluded (or there could be evidence, of course).

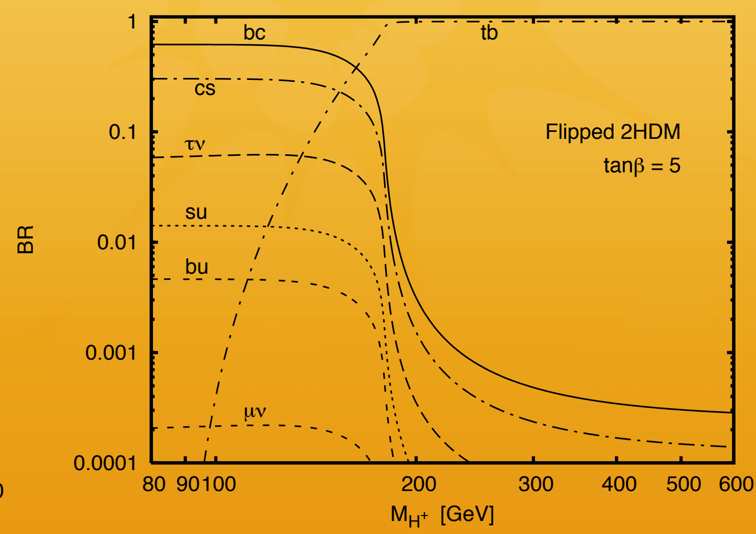
Aoki, Guedes, Kanemura, Moretti, Santos, Yagyu, 1104.3178



Guedes, Moretti, Santos (1207.4071) show that single top production will also give bounds that are somewhat weaker, but strong enough that it should be included in the analysis.

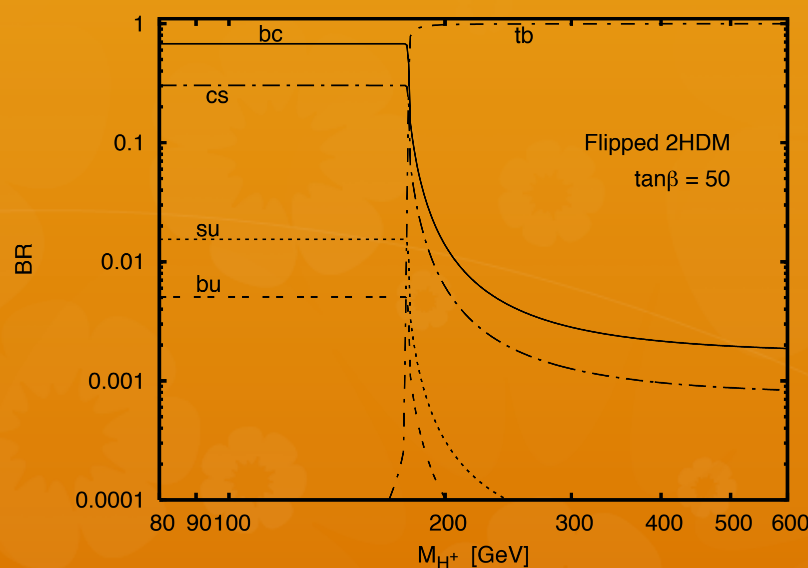
Flipped Model





For most values of tan β , the dominant decay is into bc, and the subdominant decay is into cs.

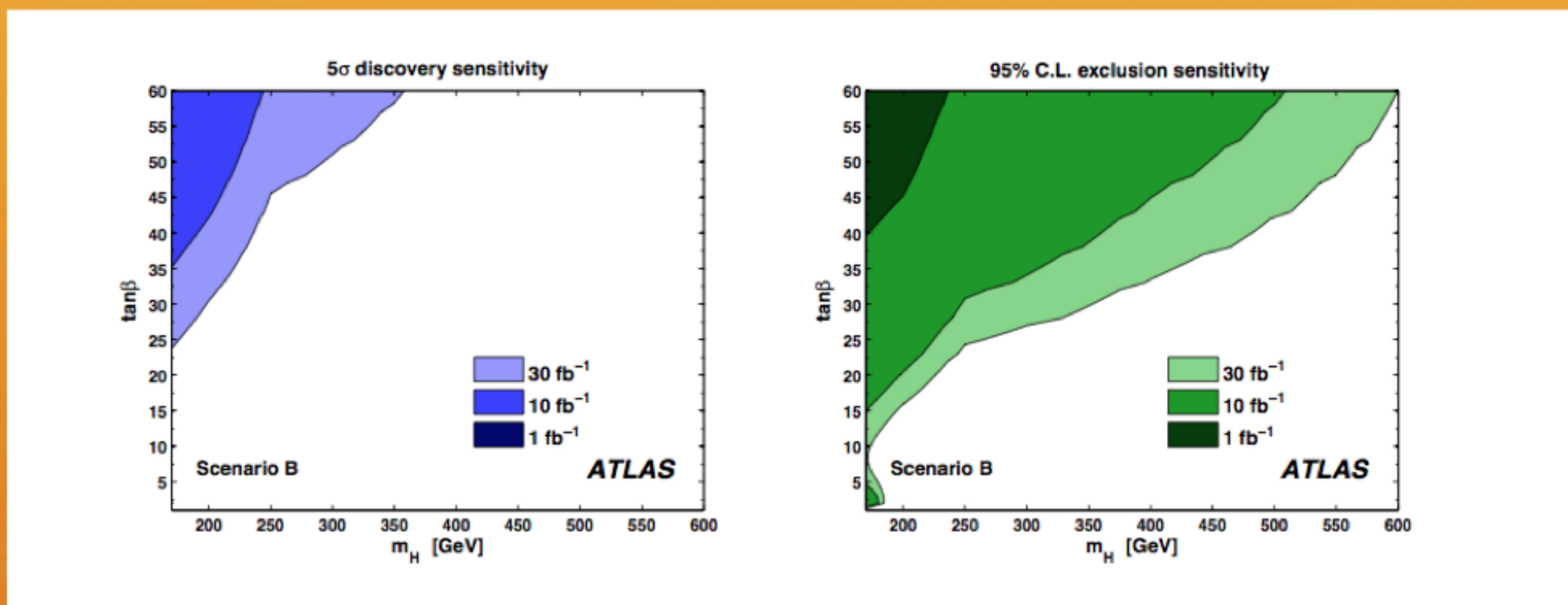
Logan, MacLennan, 1002.4916



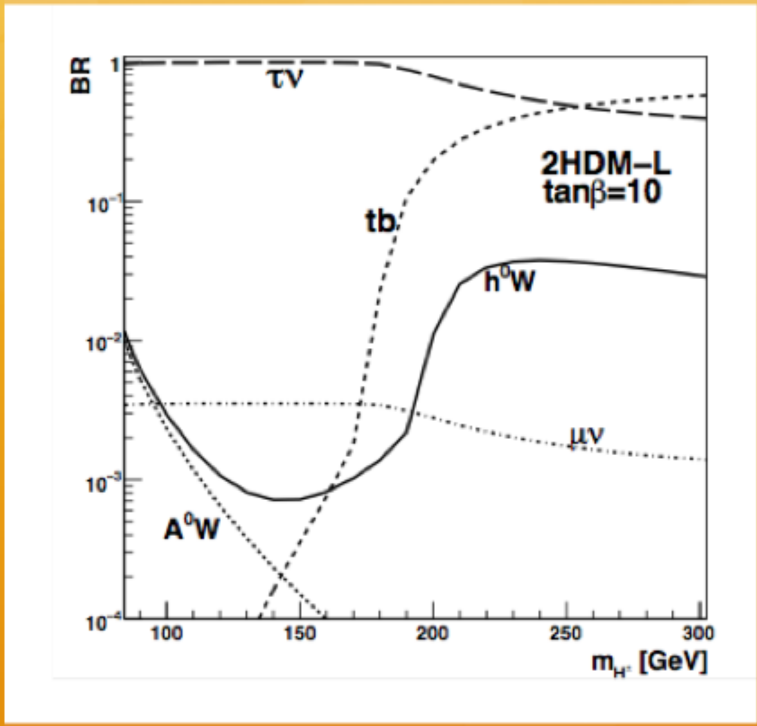
Now, suppose the charged Higgs is heavier than the top.

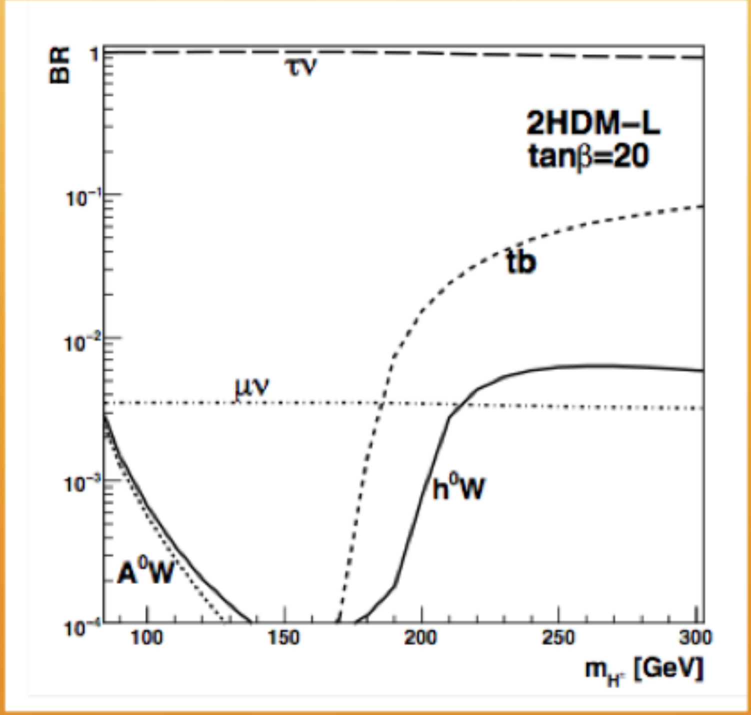
Type II model

ATLAS results for MSSM, which will not be very different from the type II model. Main production mechanism is g b → t H^-, with the H^- decaying into $\tau\,\nu$



In the lepton-specific model, branching ratios look promising:



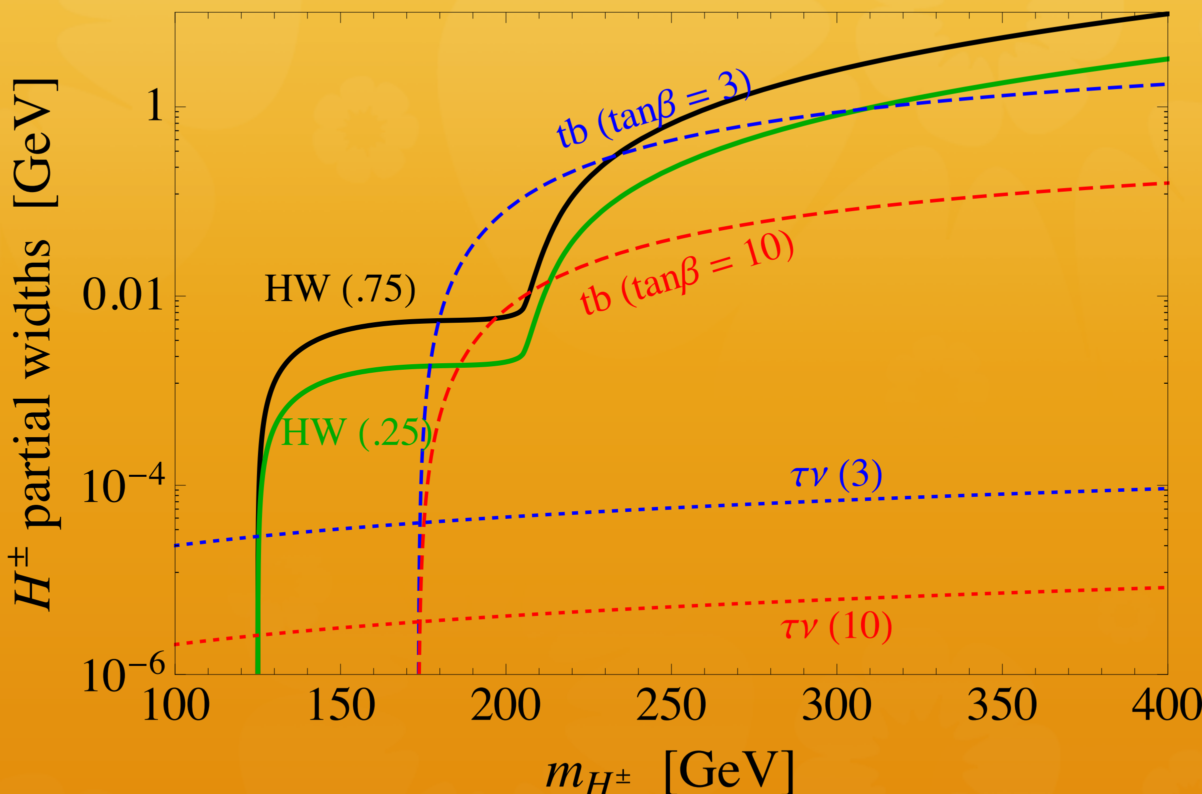


However, all quark induced production mechanisms are suppressed, and other production mechanisms are necessary.

In the flipped model, there is no chance of detecting a charged Higgs with a mass above 200 GeV

Perhaps the best hope of detection is $H^+ \rightarrow H(125)\ W^+$

Studied in 2009 by Kanemura et al 0901.0204

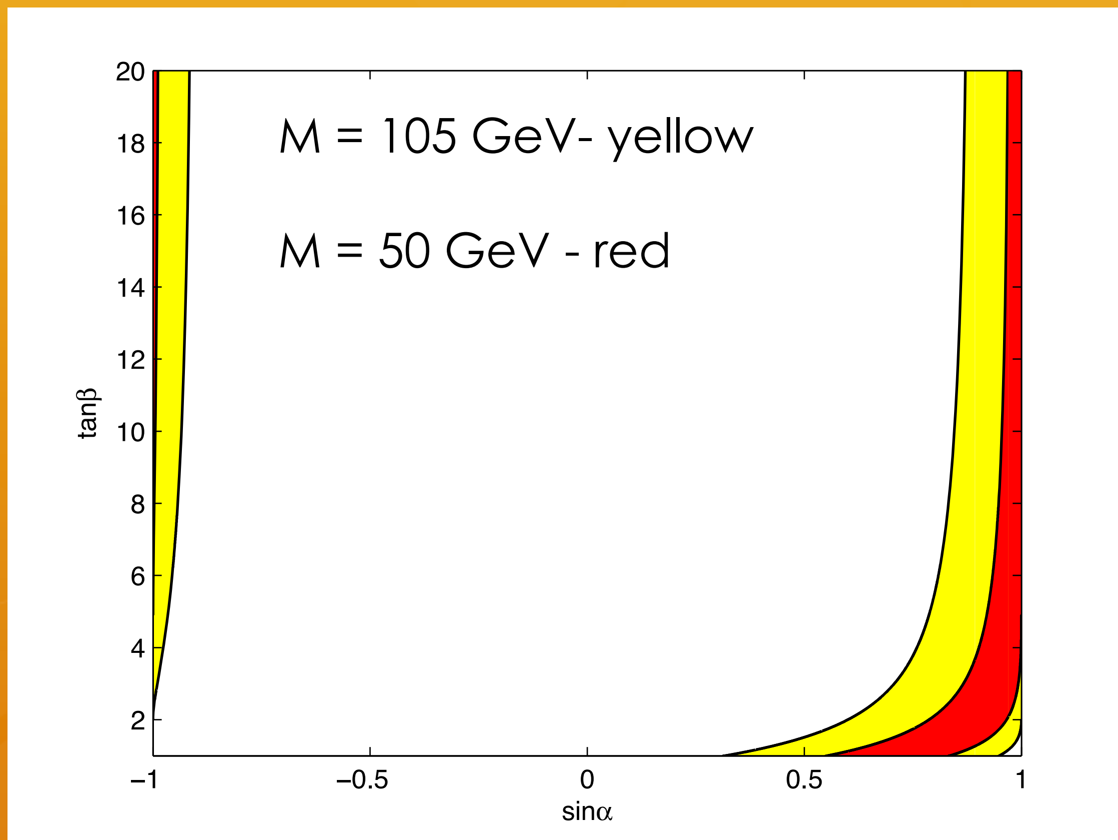


Chiang and Yagyu (1303.0168) studied $gb \rightarrow H^- t \rightarrow hW^- bW^+ \rightarrow l^+ l^- b b \bar{b}$ + missing E_T and found a signal rate in the type II model of 1-2 fb and a background of 0.05 fb . They assumed 100% b-jet identification efficiency.

MUCH more study of this, also in the type I model, is needed.

Suppose the 125 GeV scalar is the heavier.

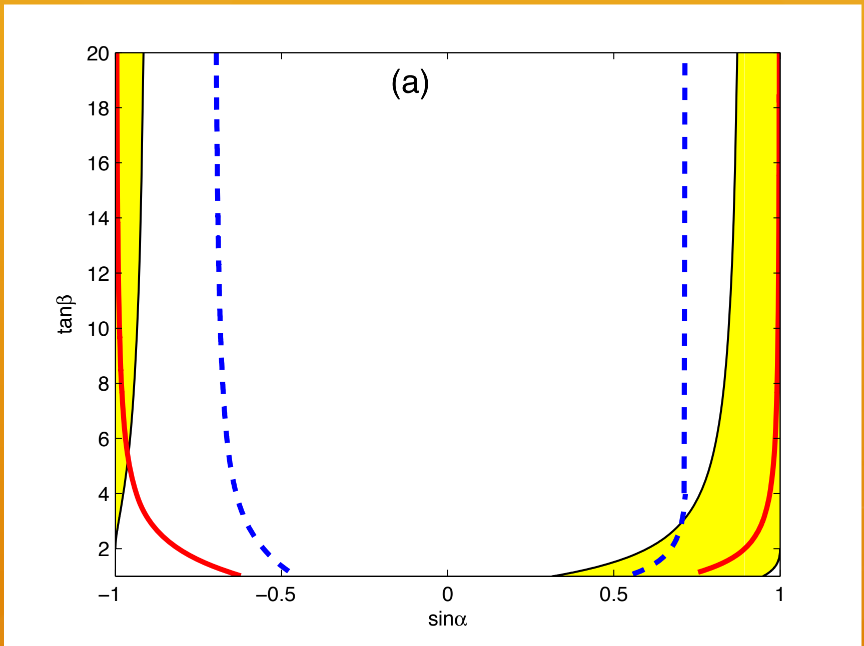
LEP bounded scalars below 114 GeV, but if the coupling to ZZ is suppressed, the bound is weakened.

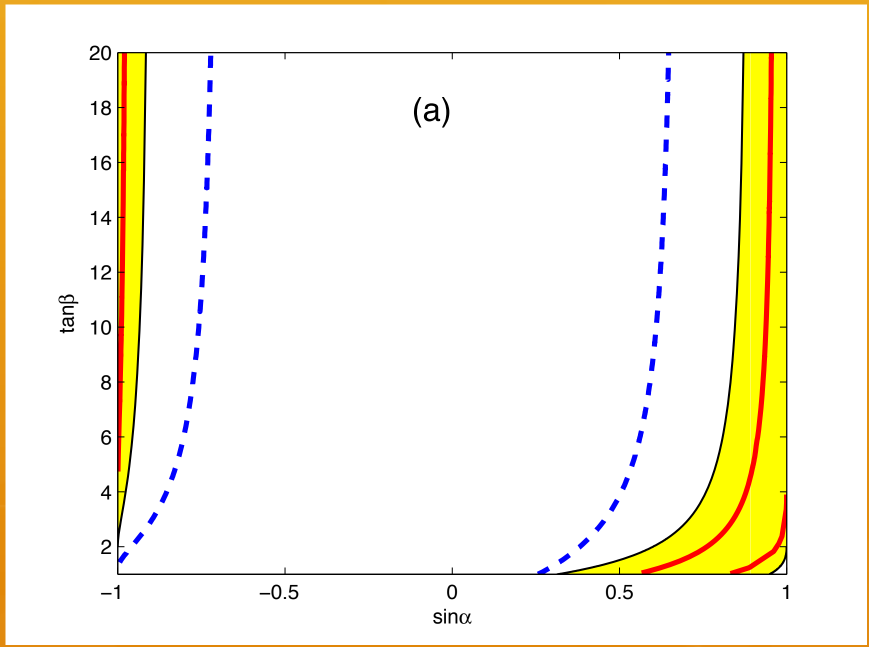


Ferreira, Santos, MS, Silva 1201.0019

If the h mass is greater than 63 GeV, H → hh is disallowed. In this case:

typical type I figures:



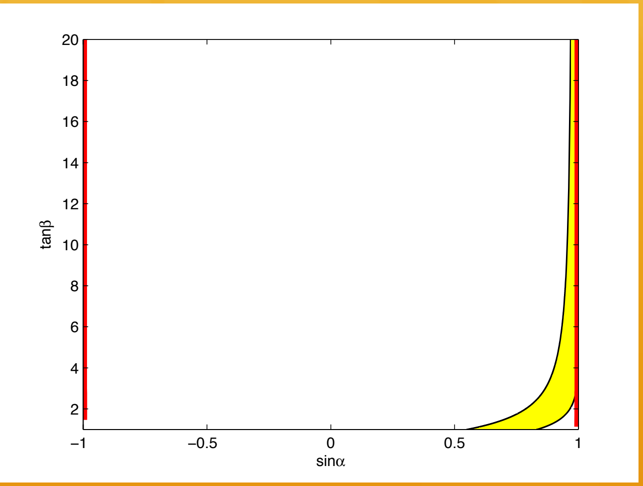


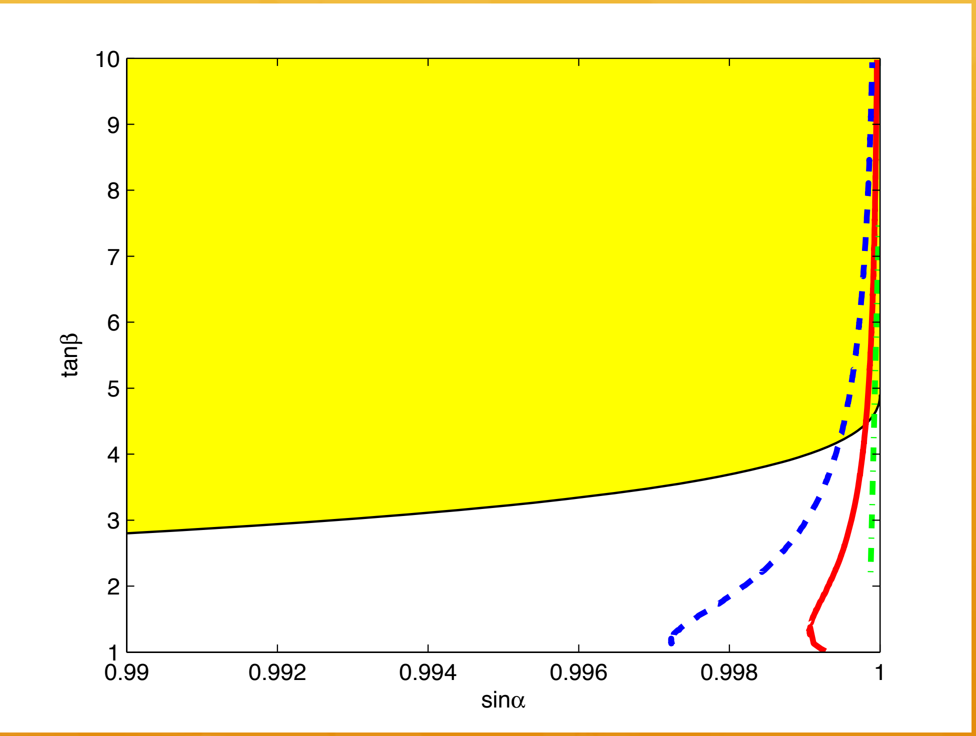
H → bb relative to SM: blue ½, red 1

H →γγ

If the h mass is less than 63 GeV, then H → hh gives strong constraints.

E.g. type II





H → γγ relative to SM, blue ½, red 1, green 2.

Conclusions

1. 2HDMs allow for very different decay branching ratios of the 125 GeV Higgs. If the SM branching ratios continue to be confirmed, 2HDMs will be more and more restricted, but can't be excluded.
2. Charged Higgs detection has been studied, but the decay into a W and an H(125) may dominate and has not been analyzed in sufficient detail yet.
3. One should always keep in mind that the lighter neutral Higgs can be lighter than 125 GeV.